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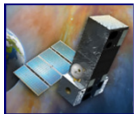

SIM Lite ASTROMETRIC OBSERVATORY

Testing of a Methane Cryogenic Heat Pipe with a Liquid Trap Turn-off Feature for Use on Space Interferometer Mission (SIM)

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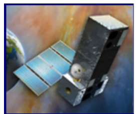
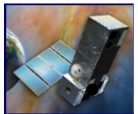
15th CONFERENCE ON THERMOPHYSICS APPLICATIONS IN MICROGRAVITY
March 7, 2011 at the Aerospace Corporation, El Segundo, CA 9009-2957



Outline

- ***Introduction***
- ***Concept***
- ***Trades***
- ***Design***
- ***Testing***
- ***Results***
- ***Conclusion***

Introduction



JPL Technical Need: *In mid-2009, JPL contacted ATK and described a need for a heat transport system (HTS) to link two CCD cameras (within the Astrometric Beam Combiner (ABC) instrument on **SIM Lite)** to a cryoradiator.*

SIM Lite: *Formerly the Space Interferometry Mission (SIM), the SIM Lite Astrometric Observatory will utilize optical inteferometry to determine the positions/distances of stars much more accurately than any previous program.*

HTS Requirements -- Normal Operation:

➢ *Hot-side temperature/range:*	*153 K / 150-156 K*
➢ *Hot-side heat load:*	*6-12 W*
➢ *Cold-side cooling source:*	*140 K cryoradiator*
➢ *Transport length:*	*1.4 m*

HTS Requirements -- Decontamination:

➢ *Hot-side decontamination temperature:*	*293 K*
➢ *Hot-side decontamination heater power:*	*Minimize*

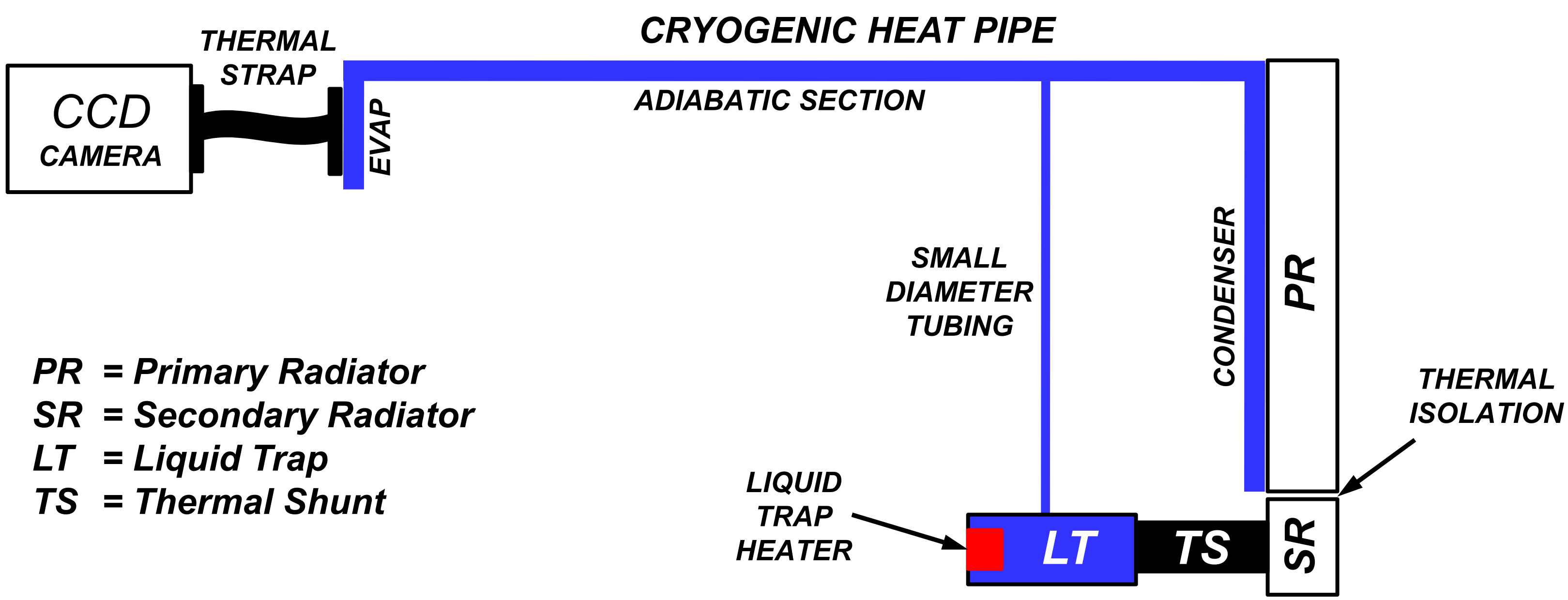
Additional Requirements:

➢ *Flight heritage:*	*Maximize*
➢ *Cost/manufacturing complexity:*	*Minimize*

Concept

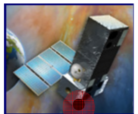
Solution: *Cryogenic heat pipe with thermal switching capability provided by a secondary radiator thermally isolated from the primary radiator, a thermally shunted liquid trap, and small liquid trap heater.*

- *During **normal operation**, the small liquid trap heater keeps the liquid trap warm enough so that it is filled with vapor only thus the heat pipe is ON.*
- *During **decontamination**, the liquid trap heater is turned off and all the working fluid migrates to the liquid trap turning the heat pipe OFF.*



***PR** = Primary Radiator*
***SR** = Secondary Radiator*
***LT** = Liquid Trap*
***TS** = Thermal Shunt*

Trades



Working Fluid:	*ethane vs.* ***methane***
Heat pipe Architecture:	***axial groove*** *vs. non-axial groove*
Flight Heritage:	***CRISM*** *vs.* ***other methane HP flight systems***
Charge Pressure:	***ambient tank*** *vs. high pressure heat pipe*
Transport Capacity:	***large diam./margin*** *vs. small diam./margin*
Radiator Sizing:	***large area, fast test*** *vs. small area, slow test*
Shunt Conductance:	*high G, speed, power vs.* ***low G, speed, power***
Evaporator Conductance:	***6” length specified by JPL*** *vs. shorter/longer*
Condenser Conductance:	***28” length specified by JPL*** *vs. shorter/longer*
Parasitics:	*environment induced vs.* ***heater induced***
Cooldown Time:	*small A, slow cooling vs.* ***large A, fast cooling***
Heater Sizing:	***ground testing ease*** *vs. system optimization*
Decontamination:	***high power*** *vs.* ***moderate power*** *vs.* ***low power***
Switching Time:	*fast, high G shunt vs.* ***slow, low G shunt***
Static Height:	*small diam., 1-g < 0-g vs.* ***large diam. 1-g > 0-g***
Structural Analysis:	*low mass, margin vs.* ***high mass, margin***
Testing:	*minimum needed vs.* ***extensive verification***

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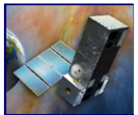
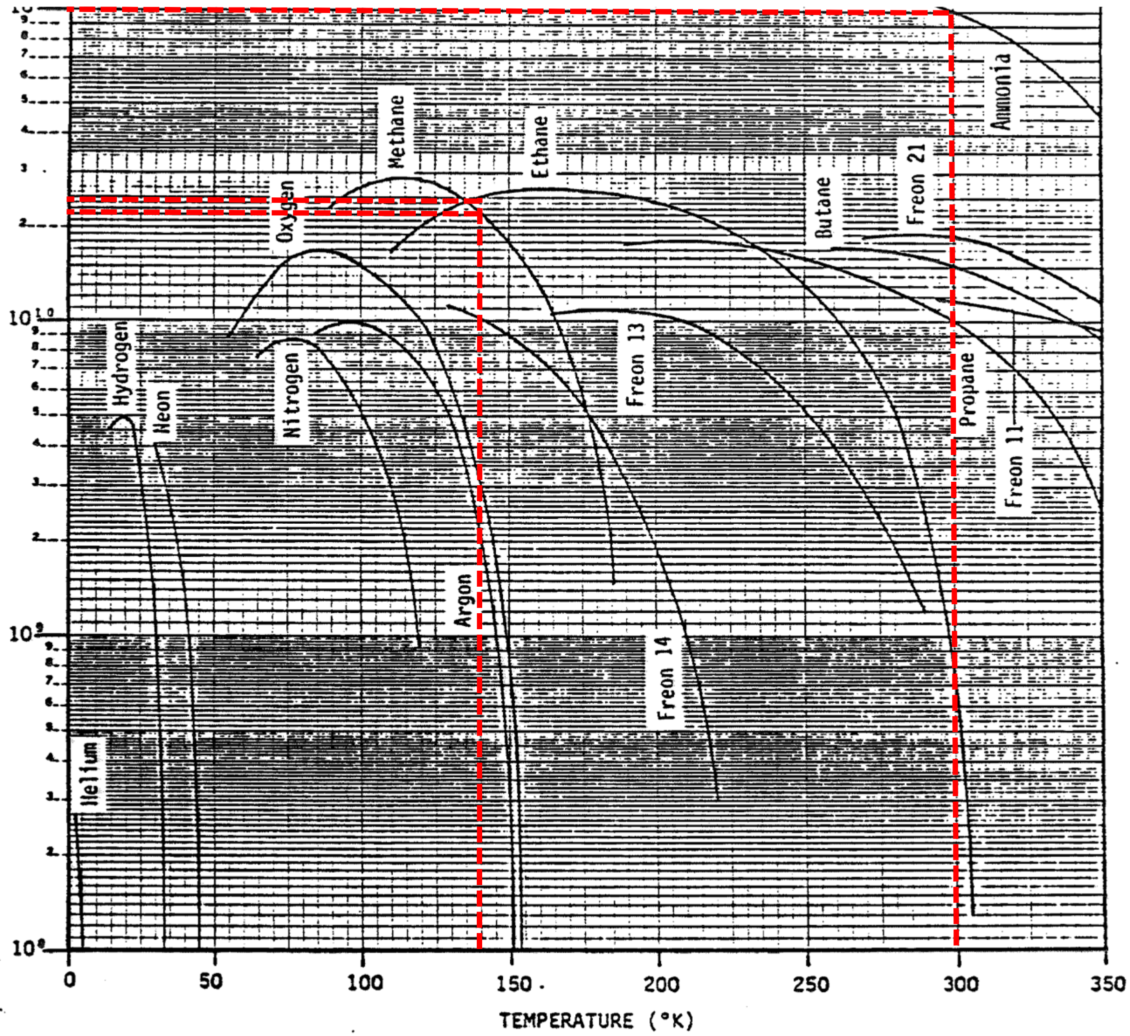
Trades



Working Fluid

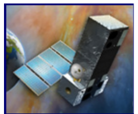


*Two possible working fluid choices for a heat pipe with a 140 K radiator (vapor) temperature are **methane** and **ethane**.*

At this temperature, the liquid transport factor (N_L) of methane and ethane are about equal and about 1/5 of that of ammonia at 300 K.

*Upon (decontamination) heating, methane liquid transport factor decreases whereas ethane liquid transport factor increases …. thus, an ethane HP will require much more heater power before dry-out occurs, making **methane a better choice than ethane**.*

$$N_L = \frac{\sigma \, \Delta H}{\nu}$$



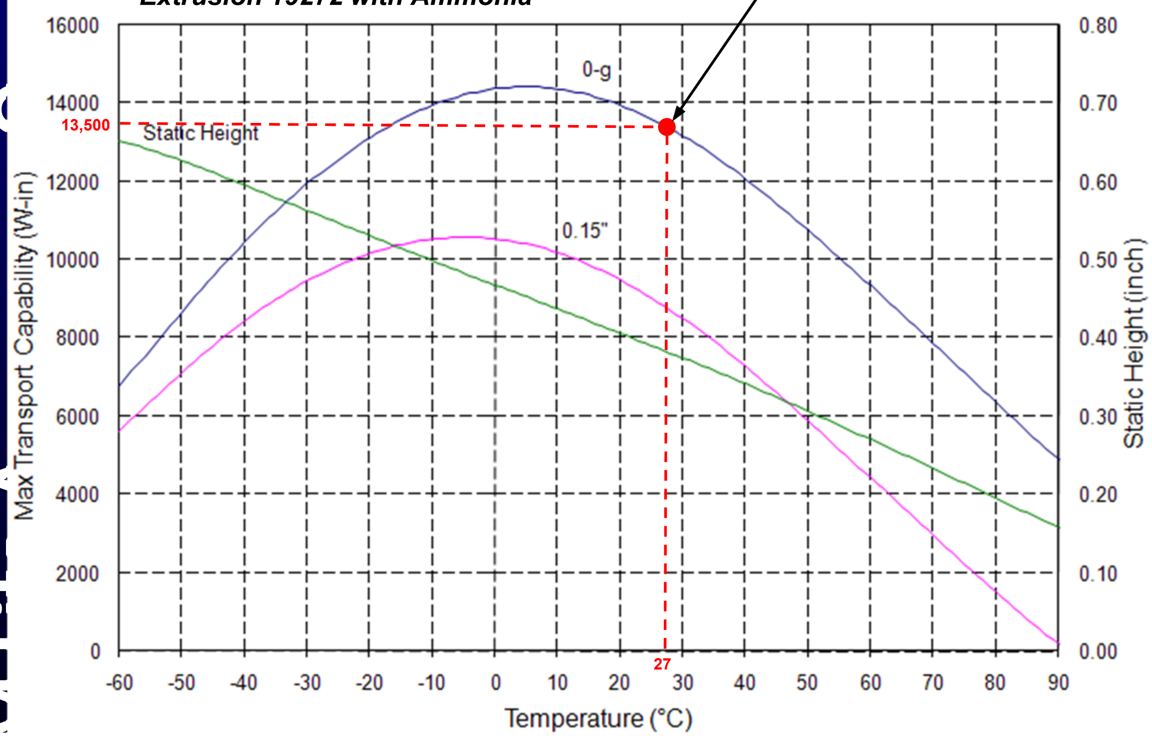
Design

Transport Capacity

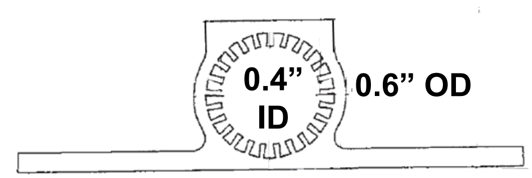
Requirement: QL = (12 W max load + 2 W parasitics) * 73.5” effective length = ***1029 W-in***

Approx. 13,500 W-in at 300 K (27 ° C)

Extrusion 19272 with Ammonia



Extrusion 19272



Transport capacity with methane at 140 K ~ 22% the transport capacity of ammonia at 300 K or ***2970 W-in****, which provides almost 200% margin on the QL requirement of 1029 W-in.*

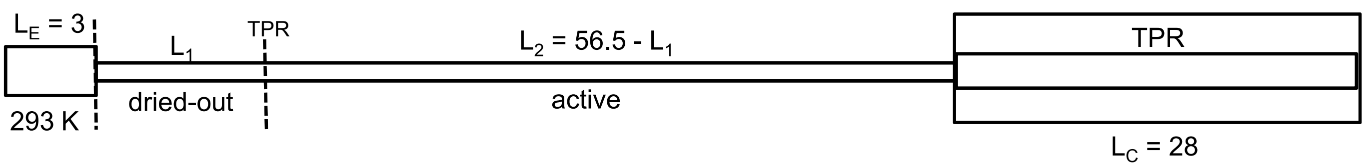
Analytical estimate of methane transport capacity at 140 K with this extrusion is ***3188 W-in.***

Design

Decontamination

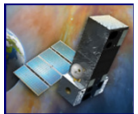
Option 1: ***High Power (Q ~ 120 W)***
- Heat primary radiator (PR) above methane critical temperature (191 K)
- Heat evaporator to 293 K (heat pipe all vapor)
- Maintain heater power on liquid trap; keep above primary radiator temperature

Option 2: ***Medium Power (40 W)***
- Heat evaporator to 293 K (evaporator dries out; part of heat pipe still works)
- Maintain heater power on liquid trap; keep above primary radiator temperature



Option 3: ***Minimum Power (3 W)***
- Turn liquid trap heater OFF
- Heat evaporator to 293 K (heat pipe evacuated by trap)

Test Outline



1. ***Initial cooling – Day 1***
2. ***Methane Radiator Test*** *- (to establish Stefan-Boltzmann constant *emissivity*area*view factor from the surface). Remove temperature control from the condenser.*
   - *High Power at evaporator*
   - *Nominal Power at evaporator*
   - *Low Power at evaporator*
3. ***Heat Pipe Characteristic Test -*** *Control the condenser radiator to a fixed temperature. Apply a heat load to the evaporator. Do several cases for several condenser temperatures.*
   - *Low condenser temp, low evaporator power*
   - *Nom. condenser temp, low evaporator power*
   - *Nom. condenser temp, nominal evaporator power*
   - *High condenser temp, low evaporator power*
   - *High condenser temp, nominal evaporator power*
   - *High condenser temp, high power – Day 2*
4. ***System Test -*** *Remove temperature control from the condenser radiator. Apply heat to the evaporator. Measure the evaporator temperature and condenser temperature*
   - *Low Power*
   - *Nominal Power*
   - *High Power*
5. ***Turn-off with hot radiator***
6. ***Decontamination -1 – Day 3***
7. ***Cool down to nominal - Day 4***
8. ***Turn-off with liquid trap – Day 5***
9. ***Decontamination -2***
10. ***End of test***

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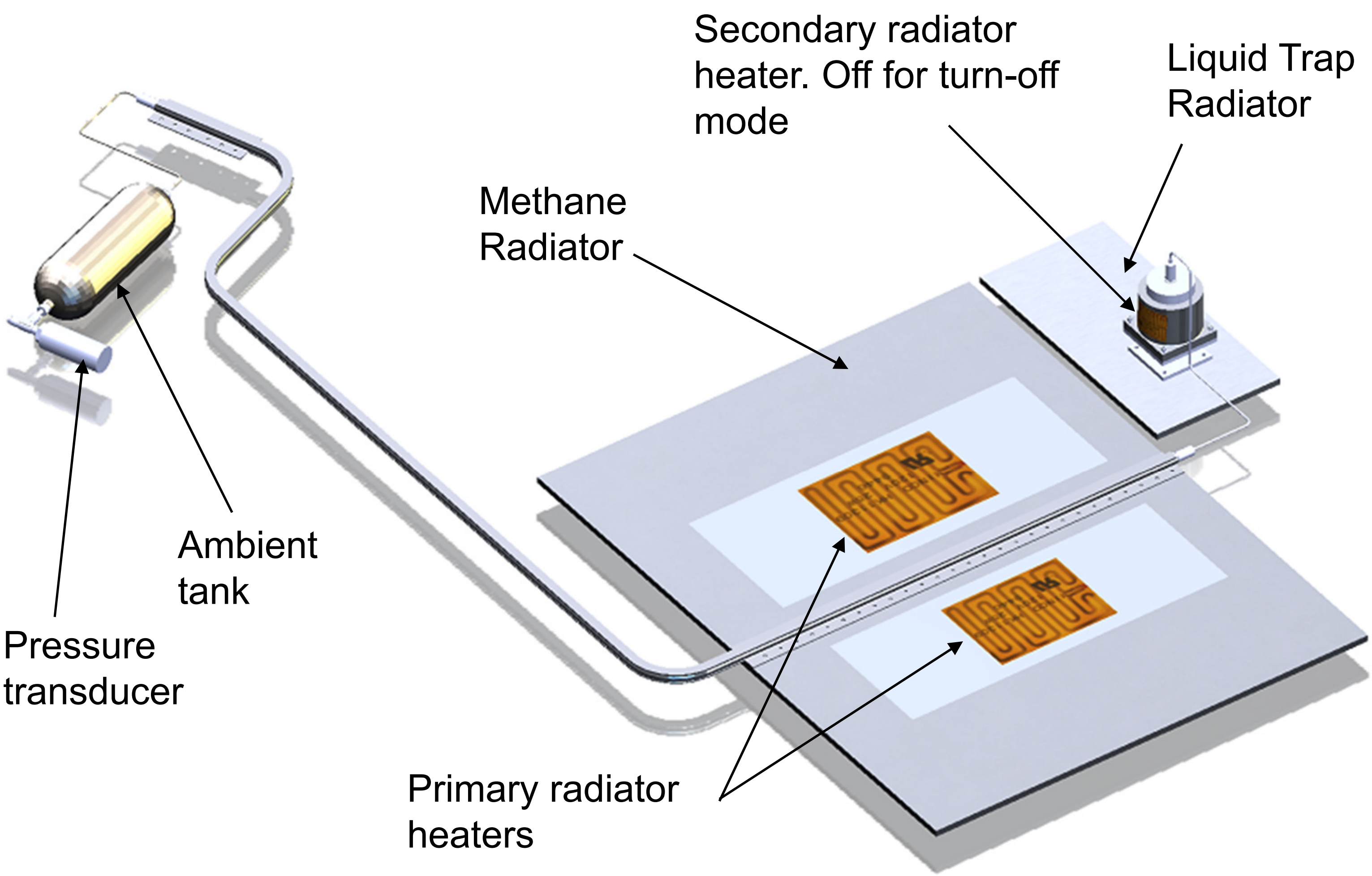
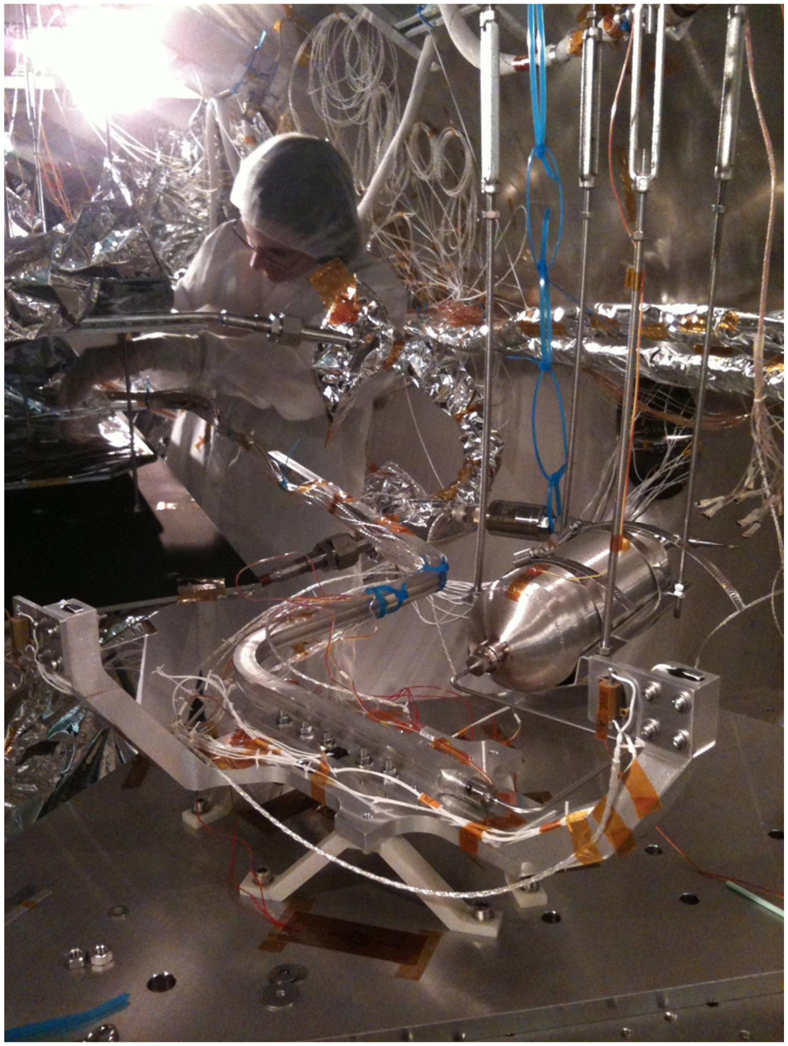
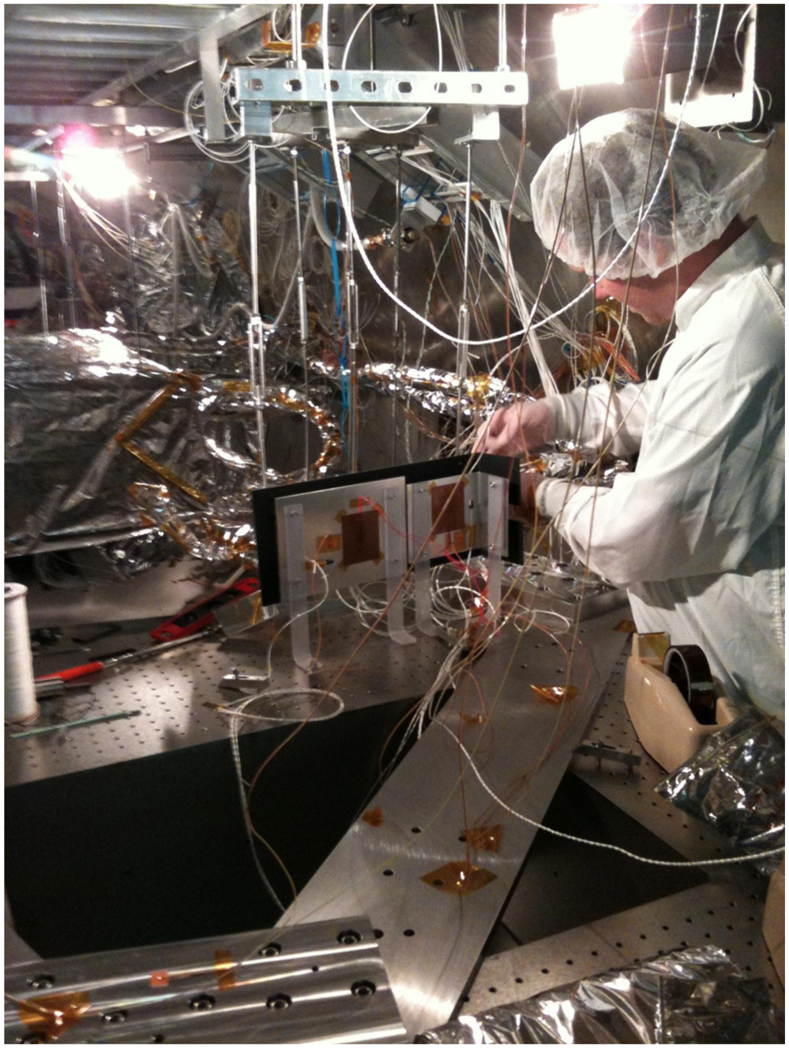
Heat Pipe with Radiators



Test Fixture Assembly





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Test Fixture Assembly - Evaporator

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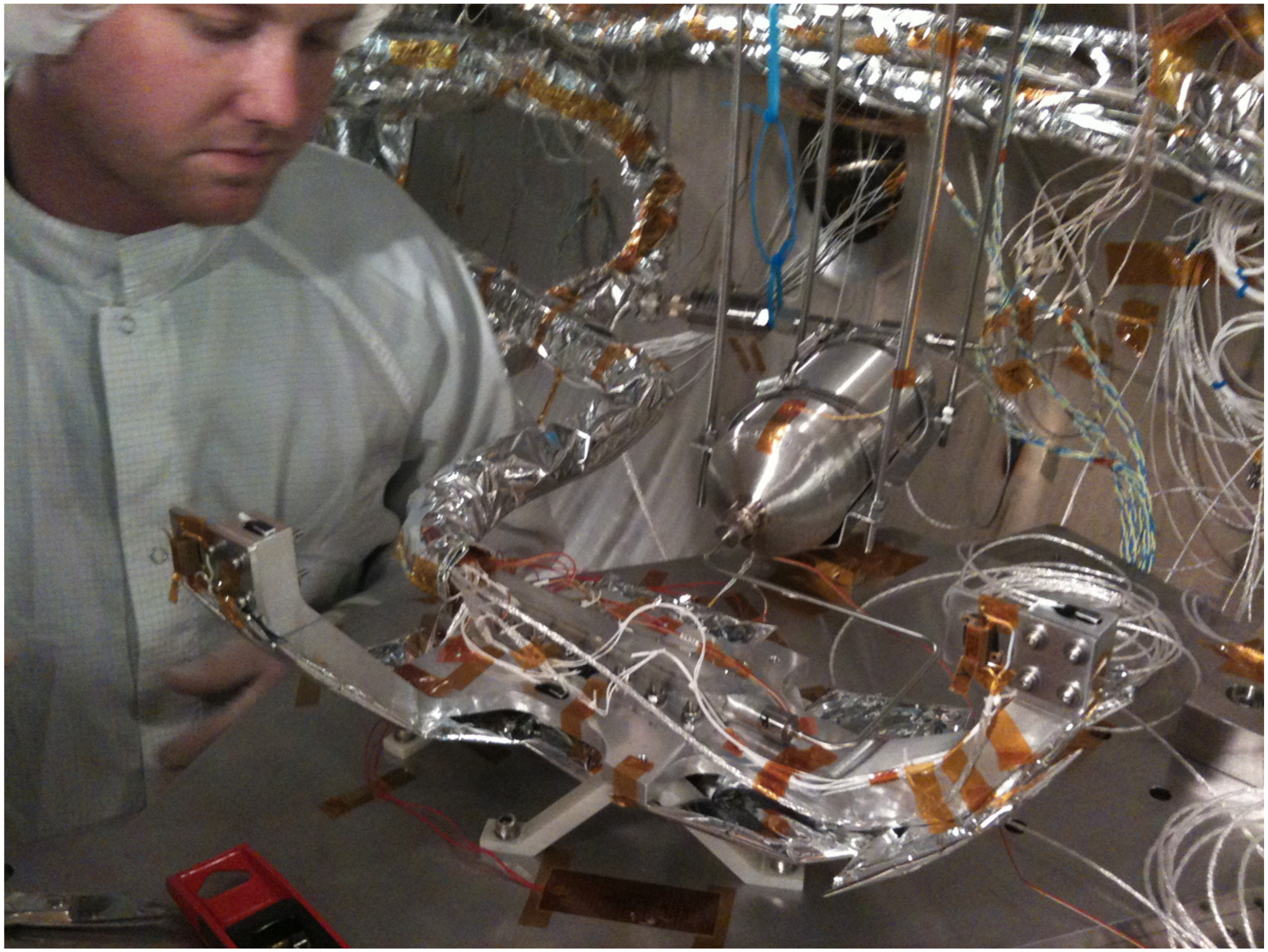

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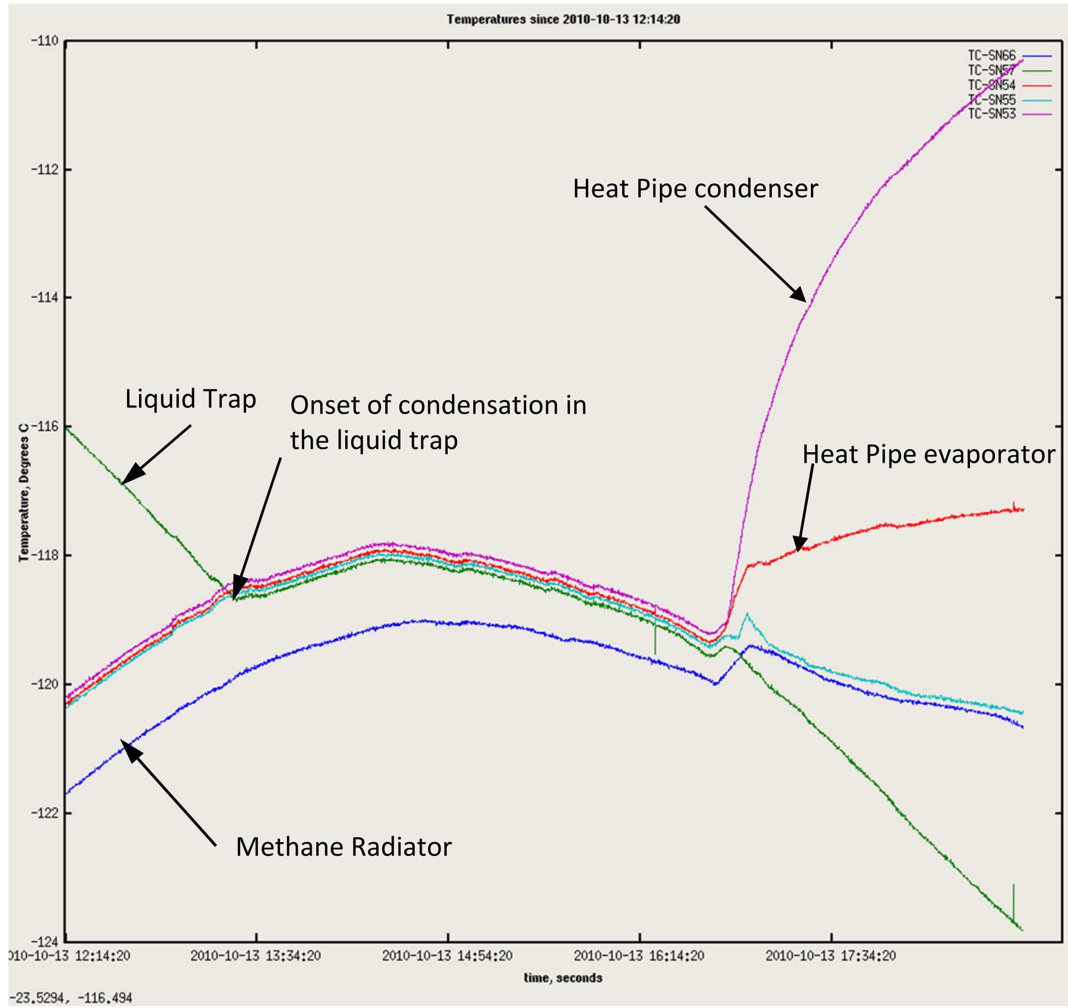
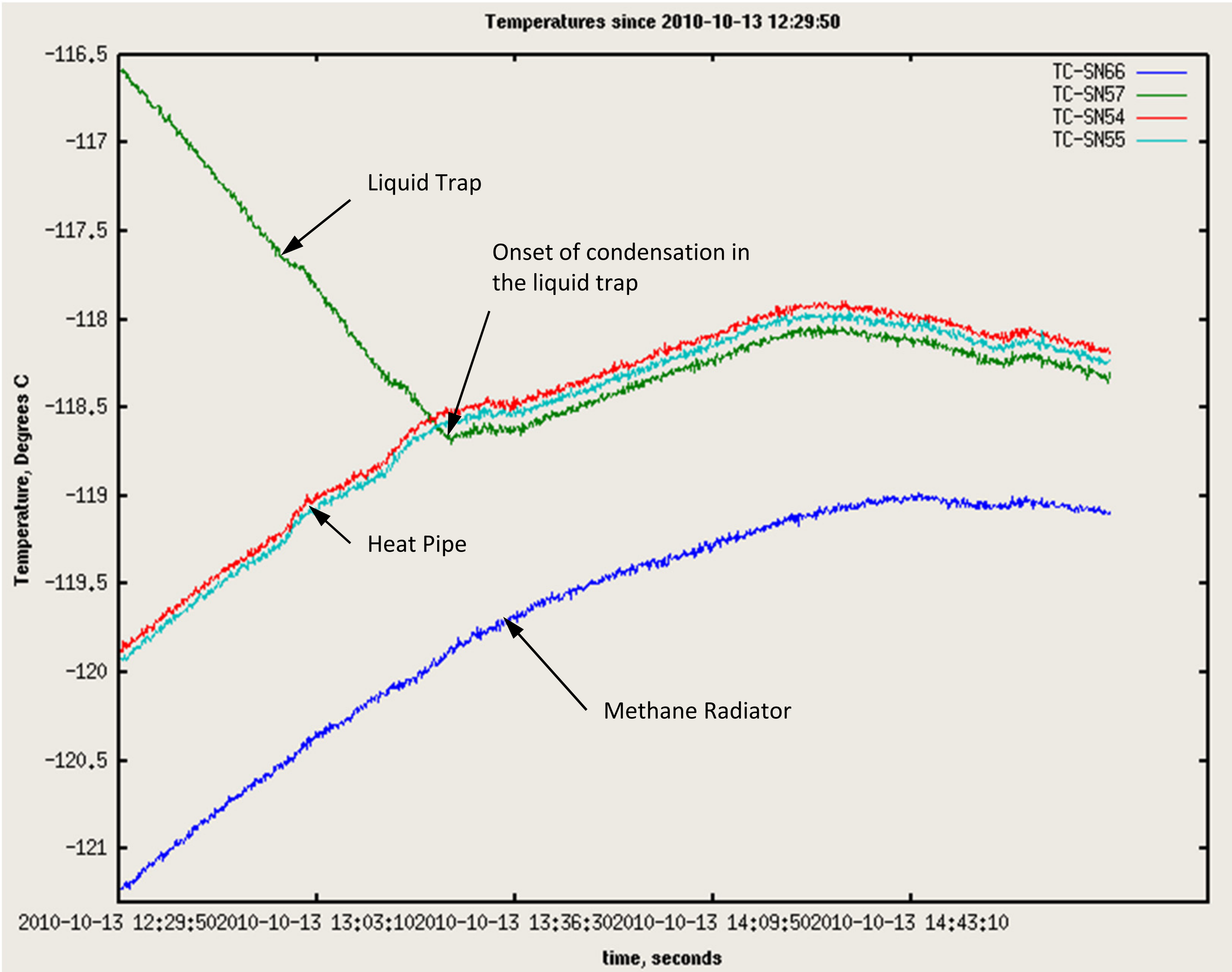
Heat Pipe Test Data, Step 2, Shut-Off Transient

SIM Lite Astrometric Observatory

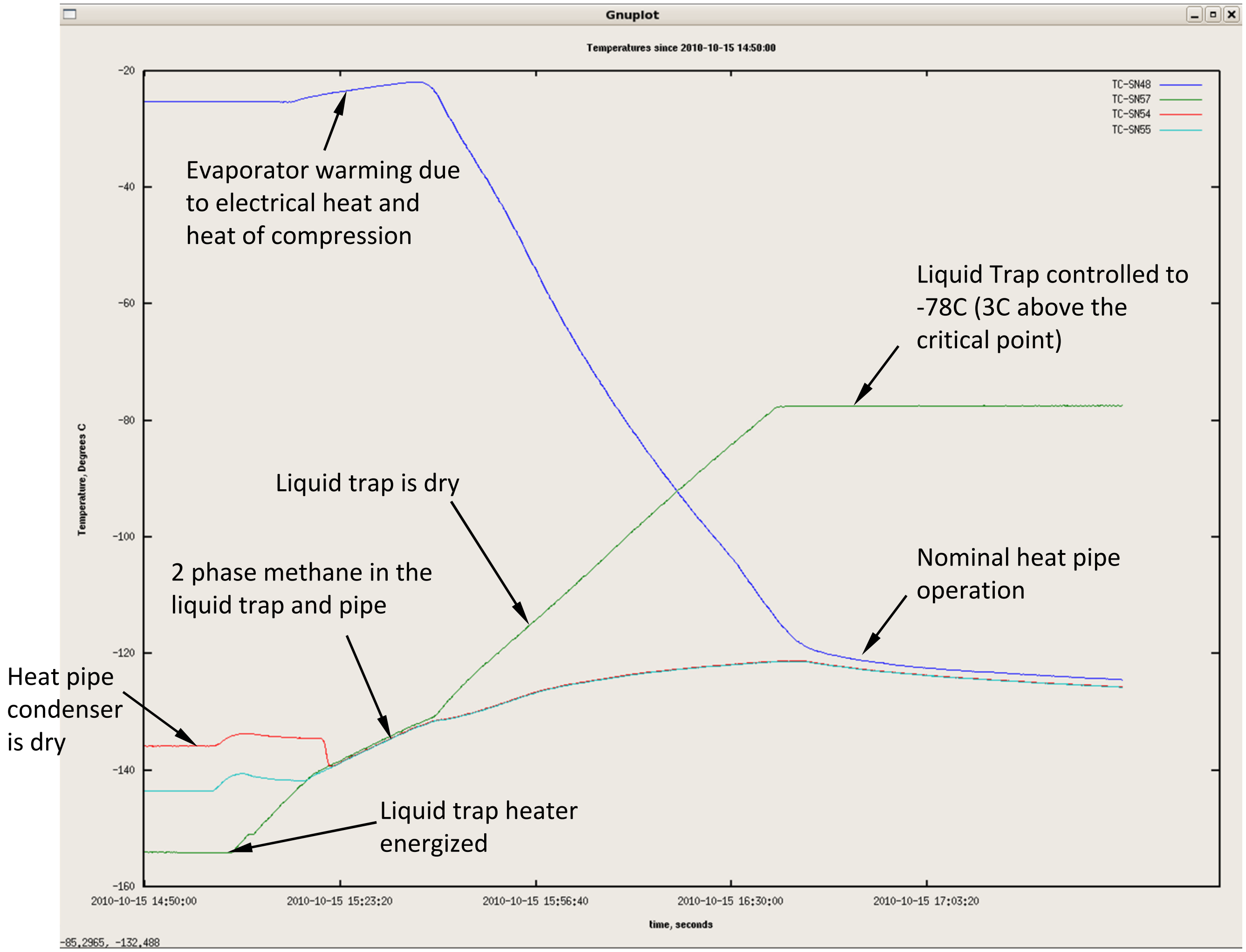
- The green line is the liquid trap. The trap cools to roughly -119C where the methane starts condensing. The magenta line is the condenser of the pipe, warming under the influence of a heater. Both items operate at the saturation temperature during the shut-down transient. It takes about 4hrs for the trap to condense the methane and dry the pipe. Then the temperatures diverge and the trap cools while the heater continues to warm the condenser.



Heat Pipe Test Data, Step 2, Shut-Off Transient



Heat Pipe Test Data, Step 5, Turn-On and Cooling



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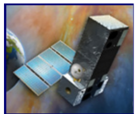
Conclusion

- Camera cooling for SIM presents three thermal control challenges; stable operation at 163K (-110° C), decontamination heating to +20° C, and a long span from the cameras to the radiator. A novel cryogenic cooling system based on a methane heat pipe meets these challenges.
- The SIM thermal team, with the help of heat pipe vendor ATK, designed and tested a complete, low temperature, cooling system. The system accommodates the two SIM cameras with a double-ended conduction bar, a single methane heat pipe, independent turn-off devices, and a flight-like radiator. The turn-off devices consist of a liquid trap, for removing the methane from the pipe, and an electrical heater to raise the methane temperature above the critical point thus preventing two-phase operation.
- This is the first time a cryogenic heat pipe has been tested at JPL and is also the first heat pipe to incorporate the turn-off features. Operation at 163K with a methane heat pipe is an important new thermal control capability for the lab. In addition, the two turn-off technologies enhance the "bag of tricks" available to the JPL thermal community. The successful test program brings this heat pipe to a high level of technology readiness.

Lessons Learned



During Procurement

- To save money, we chose to build our own test fixture to hold heat pipe in place during test.
  - Too much improvising required. It took us many days to of chamber time to configure our fixture just right. We also probably put the hardware at risk of damage, especially rupturing of the thin-walled tubing connecting heat pipe to liquid trap and ambient tank.

During Test

- Establish realistic steady-state criterion upfront. We used one K/hr, but we had to “tighten” or requirement because we saw constant drift upwards that made us feel uncomfortable with declaring steady-state reached.
- Getting to cold temperature steady-state usually takes longer than you think.
- CCD Electronic boxes were not designed for operation in a vacuum, so they heated up. They had to be cycled off and on manually to avoid overheating

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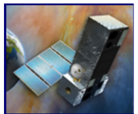
SIM Thermal Design and Test Team



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